APPENDIX A

This appendix contains a series of simplified calculations in support of the information contained in the body of this paper

A1   ELLIPSO uplink case

Uplink EIRP	=	+4.0	dBWi
Space spreading (4000 km)	=	-143.0	dB/m^2
Bandwidth (1.1 MHz)	=	-60.4	dB/Hz
PFD at ELLIPSO satellite	=	-199.4	dBW/m^2/Hz

A2   IRIDIUM uplink case

Uplink EIRP	=	-4.9	dBWi
Out of band attenuation	=	-35.0	dB
Space spreading (4000 km)	=	-143.0	dB/m^2
Demod spreading (1.1 MHz)	=	-60.4	dB/Hz
PFD at ELLIPSO satellite	=	-243.3	dBW/m^2/Hz

A3   Conversion of IRIDIUM Primary Uplink channels to Equivalent ELLIPSO Channels

Equivalent ELLIPSO channels	=	-43.9	dB	(+199.4-243.3)
IRIDIUM / ELLIPSO channels	=	+15.8	dB	
Voice activity	=	-3.0	dB	
Loading factor (100%)	=	-0.0	dB	
Average Power (2.8)	=	+4.5	dB	(20% are +10 dB)
Net Eq ELLIPSO channels	=	-26.6	dB	
	=	0.0022		

A4   IRIDIUM downlink reflection case

Downlink EIRP (nominal)	=	+7.5	dBWi
Out of band attenuation	=	-35.0	dB
Space spreading (4780 km)	=	-144.6	dB/m^2
Demod spreading (1.1 MHz)	=	-60.4	dB/Hz
Reflection loss (curvature)	=	-3.0	dB
Scatter factor	=	-10.0	dB
PFD at ELLIPSO satellite	=	-245.5	dBW/m^2/Hz

A5 Conversion of IRIDIUM downlink reflections to Equivalent ELLIPSO Channels

Equivalent ELLIPSO channels	=	-46.1	dB	(+199.4-245.5)
IRIDIUM / ELLIPSO channels	=	+15.8	dB	
Voice activity	=	-3.0	dB	
Loading factor (100%)	=	-0.0	dB	
Average Power (2.8)	=	+4.5	dB	(20% are +10 dB)
Net Eq ELLIPSO channels	=	-28,8	dB	
	=	0.0013		

Reflections from the Earth's surface are classically subdivided into two categories; specular for a smooth earth surface and diffuse for a rough earth surface. For specular reflections to exist the earth must be smooth to within a small fraction of a wavelength of the illuminating source. For the L-band case at hand a frequency of 1616.0 MHz results in a wavelength of 18.56 cm.

The reflection of radiation form the Earth's surface has been studied extensively but the complexity of the problem has prevented the development of expressions which fully describe the process. The following are typically used by industry as guidelines for differentiating between smooth and rough earth conditions. Values less than the suggested limits are considered representative of smooth earth conditions, hence specular reflection. Values greater than the prescribed limits are related to rough earth conditions and diffuse reflection.

$\Delta h \sin\theta/\lambda = 1/8$: Long, M. W. "Radar Reflectivity of Land and Sea," page 105

$\Delta h \sin\theta/\lambda = 1/4\pi$: Long, M. W. "Radar Reflectivity of Land and Sea," page 218

$\Delta h \sin\theta/\lambda = 0.3/4\pi$: CCIR Report 1008, "Reflection From the Surface of the Earth"

where: Δh = the RMS value of surface "roughness"
θ = grazing angle to a tangent plane at the Earth's surface
λ = wavelength of the illuminating source

Solving for a case representative of the IRIDIUM - Ellipsat geometry ($\theta = 90°$):

Δh = 2.32 cm or 1.48 cm (M. W. Long) or Δh = 0.44 cm (CCIR Report 1008)

The difference in limits is due primarily to the models used by the various investigators.

Since terrain heights are normally reported in peak values, the preceding RMS values must be multiplied by a factor of 2.8 which yields:

Δh(peak) = 6.5 cm or 4.1 cm (M. W. Long) or Δh(peak) = 1.2 cm (CCIR Report 1008)

One need proceed no further to conclude that the Earth is rough at L-band over the footprint of a satellite beam. CCIR Report states that the diffuse amplitude reflection coefficient lies between -14 dB and -8 dB for all practical purposes. In general industry has employed a value of -10 dB in calculations applicable to earth reflections.

5.0 REALIZABLE CAPACITY/PERFORMANCE ANALYSIS OF PROPOSED SYSTEMS OPERATING UNDER THE TECHNICAL SHARING CRITERIA

5.1 Introduction

5.1.1 Analysis Plan

This section includes an analysis of the calculated capacities and performance for the various proposed types of mobile satellite systems when operating in accordance with band segmentation. The LEO FDMA/TDMA system parameters depicted in this section correspond to the Iridium system as presented in Motorola's filings to the FCC with a reuse factor of six, which the Iridium system can achieve within the CONUS. The system parameters of the other CDMA applicants and Celsat are the most recent designs being considered by each of them as indicated within the IWG-1 Drafting Groups. The FDMA system parameters use those suggested by AMSC and depict their present estimate of parameters and capacities they may use if they were to implement an FDMA system in these bands.

Estimates of FDMA or FDMA/TDMA capacities are relatively straightforward and require knowedge of only a limited number of parameters for a particular system design. For such systems, the downlink and uplink capacities will be identical.

Estimating the capacities of CDMA systems in an interference sharing environment is more complex and is subject to variations depending upon the effects attributed to various enhancers and degraders to performance. CDMA capacity estimates are also performed for both the uplink and downlink cases separately and are not necessarily equal since several of these various capacity enhancers and degraders impact each link differently. In addition, performance requirements will also affect the estimates for capacities. For example, the capacity of CDMA systems may vary depending upon whether CDMA system operators intend to serve clear line-of-sight or faded/shadowed users, and whether they intend to serve vehicle-mounted/transportable or handheld portable subscriber units.

The analysis contained in this section attempts to show realizable capacity levels for both FDMA and FDMA/TDMA (LEO and GSO) systems and CDMA systems.

5.1.2   Power vs. Spectral Limits on Capacity

Communication systems have both power and spectral limits on channel capacity. CDMA systems are proposed to operate under an interference sharing rule which imposes power flux density limits on both the uplinks and downlinks. Use of such a rule requires that CDMA systems be power-limited. In fact, the necessity to share interference with other systems results in channel capacity significantly below the limits imposed by allocated bandwidth. A major effect of the interference sharing rule is to prevent peak power utilization either in time or over geographical areas. This means that peak traffic demands in either time or geographical area cannot be accommodated under this interference sharing rule. Thus, CDMA systems are power limited and the capacity for a geographical area, such as the contiguous United States (CONUS), is the sum of the power limited beam capacities for the composite set of beams which cover the CONUS region.

FDMA/TDMA systems are proposed to operate under band segmentation rules. Interference between systems under these rules are controlled by frequency and geographical separation. An increase in beam power to satisfy a peak traffic demand condition does not adversely affect traffic in other beams or in other systems. In fact, FDMA/TDMA systems, in contrast to CDMA systems, are designed with peak to average demand factors on the order of ten. This demand factor is accomplished notwithstanding the limits on available satellite power by two methods. First, power is conserved during the satellite orbit over regions of the earth where traffic densities are small. This conservation allows for short term peak power applications over large traffic density areas. Second, power can be transferred from beams with light traffic to be applied to heavy traffic beams. The Iridium satellite, for example, has 48 beams and one satellite can cover up to 80% of the CONUS. Thus, beam power over non-populated areas can be diverted to satisfy demand in dense traffic areas. Moreover, there are, on average, between 3 and 4 Iridium satellites covering parts of the CONUS at any one time. Power sharing between these satellites can also be used to satisfy both time and geographical peak demand. The net result is that FDMA/TDMA systems under a band segmentation rule are spectrum limited, not power limited, over a large geographical area. The channel capacity for FDMA/TDMA systems over CONUS is thus calculated as a function of the allocated spectrum.

5.2 Analysis of the Realizable Capacity for FDMA/TDMA vs FDMA/TDMA System

5.2.1 Overview

This section derives the realizable capacities for multiple FDMA/TDMA LEO systems, and shows an example of how they can share with similar systems and each other. Calculations are provided both for channel capacity and converts to spectral efficiency. Channel capacity is defined as the number of full duplex voice band channels that can be supported per geographic area in an allocated bandwidth. Spectral effiency is defined as the number of full duplex voice band channels that can be supported per megahertz of spectrum used. The derivations are general and apply to both FDMA/TDMA (channelized TDMA) systems and systems that are FDMA only. The capacity of FDMA/TDMA LEO systems will not vary for a wide range of link margins provided the satellites have sufficient power.

For the purposes of this analysis, 8.25 MHz of bandwidth is assumed to have been allocated to FDMA/TDMA systems. The channel capacities and spectral efficiencies are calculated for one through four FDMA/TDMA Iridium-type systems utilizing this 8.25 MHz allocated band. The FDMA capacity of larger or smaller band segments can be determined by calculating the ratio of the bandwidth of the alternative segment to 8.25 MHz and multiplying this ratio by the channel capacities shown for 8.25 MHz.

5.2.2 System Data Required for the Analysis

The following system parameters are required to perform the analysis.

(A) Available RF Bandwidth: The total bandwidth available for use by a specific FDMA/TDMA system.

(B) Number of Beams in the Coverage Area: The number of satellite antenna spot beams that cover the area. The areas of interest for the United States include the areas over which the FCC has jurisdiction. This includes the contiguous United States (CONUS), Alaska including the Aleutian Islands, Hawaii, Puerto Rico, Wake Island, Guam, the American Virgin Islands, and American Samoa. To facilitate easy comparisons among systems, only the CONUS capacity will be used, where it is assumed that the CDMA systems provide diversity, i.e., more than 95%

of the CONUS has two or more satellites capable of operating to a subscriber unit. In areas which are at latitudes other than those represented by the CONUS, where the CDMA systems do not have diversity, either the performance level is degraded, the capacity values are lowered, or both. The Iridium system capacity levels for non-CONUS areas are included in Annex 5.3. When other applicants finish making changes in their orbital designs and operational concepts, the areas where they can operate and the corresponding capacity levels can be determined.

(C) Cell Cluster Size (Reuse Factor): Cell cluster size is an indication of how often the frequencies may be reused by the satellite antenna beams in a coverage area. The reciprocal of the cell cluster size indicates how often the frequencies may be reused in the beam pattern. For example, a cell cluster size of six indicates that the frequencies may be reused in every sixth beam.

(D) Required Doppler Guard Band: The guard band that is required at each edge of the available RF bandwidth to accommodate the Doppler on the communication link.

(S) FDMA Channel Spacing: Spacing of the FDMA channels in the available RF Bandwidth (generally measured from center to center of the occupied bandwidth of adjacent channels).

(T) TDMA Time Slots: The number of duplex timeslots that may be accommodated in a single TDMA timeframe.

5.2.3 Uplink and Downlink Capacity Formula

The capacity of a system where the available RF bandwidth is continuous may be derived as follows:

$$\text{Capacity} = f[(A - 2D)/S] \times T \times B/C,$$

where $f[(A - 2D)/S]$ is the value of $(A - 2D)/S$ rounded down to its nearest whole number.

5.2.4 Capacity Determination for Specific Systems

5.2.4.1 CONUS Capacity for LEO FDMA/TDMA Systems

The Iridium system, as currently designed, employs the values shown below:

A = Available RF Bandwidth = 8.25 MHz (continuous)
B = Number of Beams = 59 for CONUS
C = Cell Cluster Size = 6 for CONUS
D = Required Doppler Guard Band = 37.5 KHz
S = FDMA Channel Spacing = 41.67 KHz
T = TDMA Duplex Timeslots/Timeframe = 2 for 4.8 KBPS vocoder

Table 5.2-1 shows the capacity for 1 through 4 IRIDIUM-type systems occupying a total bandwidth of 8.25 MHz.

Table 5.2-1
CONUS Capacity of Multiple FDMA/TDMA IRIDIUM Type Systems (8.25 MHz)

Number of MSS systems	4.8 Kbps Full Duplex Capacity-Channels (per system)
1	3854
2	1907
3	1258
4	924

The spectral efficiency of these systems may be determined by dividing the number of channels by the number of megahertz of occupied spectrum. Table 5.2-2 shows the spectral efficiency for 1 to 4 Iridium-type systems.

Table 5.2-2
Spectral Efficiency of Multiple FDMA/TDMA IRIDIUM-Type Systems

Number of MSS Systems	Spectral Efficiency Channels per MHz
1	467
2	462
3	457
4	453

5.3 Analysis of LEO vs GSO MSS Systems

5.3.1 Overview

This section derives the realizable capacities for FDMA GSO systems. Values are again provided for both channel capacity and spectral efficiency.

For purposes of this analysis, an allocated bandwidth of 8.25 MHz is used. Within this band segment, the channel capacities are calculated for one through four hypothetical FDMA GSO systems similar to the one proposed by AMSC.

5.3.2 System Data Required for the Analysis

The system parameters required to perform this analysis are the same ones identified in Section 5.2 above. GSO systems, however, will not need a Doppler guardband at the edge of the available RF bandwidth.

5.3.3 Uplink and Downlink Capacity Formula

The capacity of a system where the spectrum, A, is continuous, may be written as follows:

Capacity = f[A/S] x T x B/C,

where f[A/S] is the value of A/S rounded down to its nearest whole number.

5.3.4 CONUS Capacity Determination for Specific Systems

A hypothetical FDMA GSO system could employ the values shown below:

A = Available RF Bandwidth =   8.25 MHz (uplink)
                                  8.25 MHz (downlink)
B = Number of Beams = 6 for CONUS
C = Cell Cluster Size = 1.5 for CONUS
S = FDMA Channel Spacing = 8 KHz
T = TDMA Duplex Timeslots/Timeframe = 1 for FDMA only

Tables 5.9-1 shows the capacity for 1 through 4 GSO-type systems occupying a total bandwidth of 8.25 MHz uplink and 8.25 MHz downlink.

Table 5.3-1
**CONUS Capacity of Multiple FDMA GSO-Type Systems
in 8.25 MHz (Uplink and Downlink)**

Number of MSS systems	Capacity-Channels (per system)
1	4125
2	2062
3	1375
4	1031

However, to close the link from geostationary orbit, power levels beyond the -142 dBW/m^2/4KHz are required as shown below. An FDMA GSO capacity reduction will result from any PFD limit that will be imposed on the 2483.5-2500 MHz band. It is assumed for the purpose of this analysis that a minimum amount of spreading will be used so that the PFD thresholds can be met. The capacity versus PFD threshold, based on the capacity numbers of Table 5.3-1 are summarized below: The monimal operating PFD of the system without spreading is assumed to be -134 dBW/m^2/4KHz.

Table 5.3-2
**CONUS Channel Capacity as a
Function of PFD Level (8.25 MHz)**

PFD Level (dBW/m^2/4KHz)	Channel Capacity/System
-134	4125
-136	2602
-138	1642
-140	1036
-142	653

Given the most restrictive PFD level, the capacities of Table 5.3-2 are shown in Table 5.3-3.

Table 5.3-3

PFD-Limited CONUS Capacity of Multiple FDMA GSO-Type Systems in 8.25 MHz (Uplink and Downlink)

Number of MSS Systems	Capacity Channels (per system)
1	653
2	326
3	217
4	163

The spectral efficiency of these systems can easily be determined by dividing the number of channels by the number of megahertz of occupied spectrum. Table 5.3-4 shows the spectral efficiency for 1 to 4 FDMA GSO-type systems.

Table 5.3-4
Spectral Efficiency of Multiple FDMA GSO-Type Systems

Number of MSS Systems	Spectral Efficiency Channels per MHz
1	79
2	79
3	79
4	79

5.3.5   Sharing between an FDMA/TDMA LEO System and an FDMA GSO System

For the purposes of this analysis, it is assumed that the Iridium™ system and the hypothetical FDMA GSO-type share spectrum in the 8.25 MHz of the L-band spectrum, and that the GSO system operates in the CONUS at the -142 dBW/m^2/4KHz level, and has operated long enough to claim one-third of the spectrum allocated for FDMA/TDMA and FDMA systems. Therefore, this example computes the capacity in 8.25 MHz if the Iridium™ system uses 5.5 MHz of the L-band spectrum and the GSO system using 2.75 MHz of the L-band spectrum. It is further assumed for

purposes of this analysis that the GSO system is also using 2.75 MHz of downlink spectrum at S-band, although the GSO system could use all 8.25 MHz of the S-band spectrum if it chose to do so. The remaining 5.5 MHz of S-band spectrum would be available for other uses.

Using the formulas from the previous sections and only considering service to the CONUS, the Iridium system and the GSO system generate the following overall capacities:

Table 5.3-5
CONUS Capacity (Channels) from FDMA LEO and GSO Systems in 8.25 MHz of L-Band Spectrum

System	Spectrum	4.8KBPS Channels
Iridium	5.5 MHz (L)	2556
GSO-FDMA	2.75 MHz (L) 2.75 MHz (S)	217
Total	8.25 MHz (L) 2.75 MHz (S)	2773
Total Spectral Efficiency (per MHz)		252

5.4 Analysis of Realizable Capacities for CDMA vs CDMA Systems

5.4.1 Introduction

The capacities of CDMA systems under a band segmentation proposal have been determined assuming that CDMA systems are allocated 8.25 MHz of uplink spectrum and 8.25 MHz of downlink spectrum. The analysis was done both on a system-by-system basis using the applicants' recent system design concepts and under the assumption that multiple CDMA systems would share spectrum by controlling their interference using a channelized CDMA architecture. Both the uplink and downlink capacities were analyzed. The overall system capacity is the lower of the uplink and downlink capacities. The effect on the downlink and the uplink of several potential capacity/performance degraders and enhancers also has been calculated.

The method of calculating the CDMA capacity is identical to the technique proposed by the CDMA applicants (IWG1-38 and IWG1-56). This technique is based on the interference sharing analysis developed by CELSAT, (IWG1-16, 17 and Annex 5.1, Drafting Group A report). This calculation method is used on both the uplinks and downlinks. For the uplink, there is a dynamic range limitation in portable handset usage. This limitation arises because of either design constraints or public safety limits. After the calculation of the uplink capacity using the Barnett/Malinckrodt method, the capacity result is modified to include the effects of terminal dynamic range. This capacity modification (IWG1-57, IWG1-64) computes the reduction in capacity necessary to accommodate interference sharing when the terminal dynamic range is exhausted. Results will be presented with and without the dynamic range effects as the latter applies to vehicular and other non-handset users.

Beyond the dynamic range modification for uplink capacity, there is also some disagreement between the CDMA and FDMA factions concerning certain variables which impact capacity and performance. This disagreement, however, is small and does not greatly affect the capacity calculations. For example, the uplink average propagation margin estimated by the CDMA proponents varies between 1.0 and 2.0 dB. The fade model developed herein generates a value of 1.4 dB. The downlink average propagation margin estimated by the CDMA proponents varies between 2.0 and 2.6 dB whereas the fade model gives a value of 2.5 dB. The fade model derives these values based on a dual satellite path diversity implementation of the CDMA systems. For the channel activity factor, this report assumes a value of 0.5 as a minimum realistic value for cellular type systems. The CDMA proponents use values which range from 0.35 to 0.5 dB.

In the CDMA analysis to follow, the value of cross-polarization discrimination is taken as 0 dB. Assuming that low values of cross-polarization discrimination, e.g., 3 or 6 dB, can be used for interference protection between systems results in unacceptably high interference when the user experiences fading and the cross-polarization discrimination disappears. Experimental data does support the presence of some discrimination for clear sky users but there is general agreement that there is no discrimination when the signal undergoes fading.

5.4.2   Realizable Uplink Capacities

The analysis of uplink capacities for CDMA systems operating in an

interference sharing environment requires the use of numerous system parameters and several equations to reflect overall performance. First, individual system capacities are derived for each of the proposed CDMA systems, and second, combined capacities are derived by analyzing the interrelationship between the systems.

5.4.2.1   System Data Required for Analysis

The following system parameters are required to perform this analysis. Each parameter is briefly defined and described below.

(A_u)   Baseband Bit-Rate

This is the total uplink baseband bit-rate required for a single voice channel. It should include all signalling overhead.

(B_u)   Channel Activity Factor

This parameter (which should be between zero and one) should be included if the system intends to exploit voice activity by reducing the uplink transmit power during the nautral pauses in speech. This parameter is the numerical ratio of the average power to the peak power accounting for only the power reductions attributed to pauses in speech. Alternatively, if some form of Digial Speech Interpolation (DSI) is implemented, which produces a corresponding channel efficiency gain, this should be included here as the inverse of the average number of virtual channels multiplexed in an individual signal.

(C_u)   Total RF Bandwidth

This is the total occupied uplink RF bandwidth used by the system.

(D_u)   Minimum Operating Eb/No

This uplink parameter, which is a function of the modulation scheme and modem implementation, is normally represented in dB form, but needs to be converted to a linear power ratio to substitute in the capacity equation.

(E_u)   Number of Satellite Beams to Provide CONUS Coverage

This is the total number of uplink beams, irrespective of the number of satellites, used to implement CONUS coverage. If there are separate satellites in the same system providing co-coverage, the beams in the areas of overlap should only be counted once.

(F_u) Beam Frequency Re-Use Factor

This parameter is a measure of the degree to which the uplink frequency band is re-used spatially among the beams. The value of this parameter is "N", where frequencies are re-used once in every "N" beams. For example, a system with re-use in every beam has a value of N=1. A system with full frequency re-use in every third beam has a value of N=3.

(G_u) Average Propagation Margin

This is the uplink power margin required, in dB, at any instant in time, averaged over all the users in the CONUS coverage of the system, used to overcome propagation impairments relative to free space.

(H_u) Average Orbit and Beam Effects

This parameter takes account of the combined effect of uplink range differences and uplink antenna gain contour effects. It is essentially a dB value that is equivalent to the average extra user mobile terminal power required to communicate with the satellite, assuming that all the users are distributed throughout the CONUS coverage, compared to the situation if all those users were located at the optimum location in the coverage area where G/R^2 is at a maximum (G = satellite antenna gain; R = range to the satellite). It accounts for the difficulty of building a perfect satellite antenna.

(J_u) Average Power Control Implementation Margin

This is a dB value which is a result of imperfect uplink power control. It is equal to the average amount by which the link power exceeds the minimum necessary to sustain the link, if power control were perfect.

(K_u) Average Beam Overlap Factor

This takes account of the spillover between uplink beams. It is the ratio, in dB, averaged over all the users throughout the CONUS coverage, of the power arriving in the intended plus adjacent beams to the power arriving in the intended beam only. Its value is highly dependent on the Beam Frequency Re-Use Factor (see item (F_u)) above).

(N_u) **Terminal Dynamic Range Factor**

This takes into account the finite dynamic range of the earth terminal. The factor is equal to the ratio of maximum to minimum terminal output power. The maximum output power is fixed by peak power design limitations and potential health limits (especially for handsets).

(Pu) **Maximum Average Propagation Margin**

This is the maximum uplink average power margin, as a ratio, used to overcome propagation impairments relative to free space. It corresponds to the largest average factor increase over nominal conditions which the adaptive power control system can produce. The averaging time of this margin is much larger than the short term fading intervals.

(Q_u) **Diversity Combining Loss Factor**

This loss factor in ratio represents the additional E_b/N_0 required in dual diversity combining relative to ideal combining. The major contributor to this loss is the inability of a non-coherent receiver to perfectly align delay-offset waveforms. This factor is more significant on the uplink because there is no pilot signal to aid in combining and demodulation.

5.4.2.2 Uplink Analysis Method

The uplink analysis method can be split into several parts. First, for each system, calculate maximum realizable uplink capacity (C_{MRU}) using the following formula:

$$C_{MRU} = (C_u \cdot E_u) / (A_u \cdot B_u \cdot D_u \cdot F_u \cdot Q_u)(10^{\wedge}(\Delta_u/10))$$

where $\Delta_u = G_u + H_u + J_u + K_u + Q_u$

The next stage in the analysis is to derive the uplink capacity for each system, which relates the realizable capacity of the system to the maximum operating uplink EIRP areal-spectral density, E_{su}, for varying amounts of interfering co-polar uplink EIRP areal-spectral density, E_{iu}, due to other sharing systems. This is calculated as follows:

First, it is necessary to calculate the effective thermal noise equivalent uplink EIRP areal-spectral density in a 4 kHz bandwidth, E_{nu}, which is given by the following equation:

$$E_{nu} = (k \cdot T_s) / 0.00276$$

where: k = Boltzmann's constant ($=-228.6$ dBW/Hz·K))

T_s = Satellite receive system noise temperature (typically = 500K or 27.0 dBK)

This equation gives a value for E_{nu} of -140.0 dBW/m^2/4KHz, assuming that T_s is 500 K. This is the equivalent uplink EIRP areal-spectral density at the Earth's surface that would be required to produce the satellite receive system noise temperature corresponding to 500 K.

The realizable capacity, C_{RU}, of the system, when operating without other interfering systems present, can now be related to the maximum realizable uplink capacity, C_{MRU}, the maximum operating uplink EIRP areal-spectral density in a 4 kHz bandwidth, E_{nu}, by the following equation:

$$C_{RU} = (C_{MRU} \cdot E_{su}) / (E_{su} + E_{nu})$$

The impact of interfering co-polar uplink EIRP areal-spectral density from other co-frequency systems, E_{iu}, can also be taken into account using the following equation:

$$C_{RU} = (C_{MRU} \cdot E_{su}) / (E_{su} + E_{nu} + E_{iu})$$

This equation must be modified to consider the dynamic range factors N_u and P_u. The effect of dynamic range is to reduce maximum fade margin as the number of interfering systems rises.

The modification of the above equation to reflect the dynamic range effect is as follows. Define the dynamic range margin as the ratio of the terminal dynamic range factor N_u and the maximum average propagation margin, viz.,

$$DRM = N_u/P_u$$

This quantity represents the extra terminal power "headroom" to accommodate power increases required as additional sharing systems are added. It is assumed that DRM is greater than unity, i.e., the link can be closed under shadowing conditions at the required fade margin P_u.

Under an equal allocation of interference with P systems, the above capacity equation can be indexed on the number of systems by

$$C_{RU}(P) = C_{MRU}/(P+E_{nu}/E_{su}) \tag{5.1}$$

This equation is valid provided the dynamic range margin satisfies

$$DRM \geq (1+PE_{su}/E_{nu})/(1+E_{su}/E_{nu}) \tag{5.2}$$

When this condition is not satisfied, the capacity must be reduced in order to maintain the fade margin objectives. The capacity, limited by dynamic range, is derived in Annex 5.1 of this report as

$$C_{LRU}(P) = C_{RU}(1)F_{dr}/D, \quad F_{dr} \geq 0 \tag{5.3}$$

where the dynamic range capacity factor F_{dr} is

$$F_{dr} = DRM-P+1+(DRM-1)E_{nu}/E_{ns} \tag{5.4}$$

The channel capacity is given by Eq. (5.1) when Eq. (5.2) is satisfied and by Eq. (5.3) when it is not. The theoretical development of this modification is provided in Annex 5.1 of this report.

5.4.2.3 Results of Uplink Analysis

5.4.2.3.1 Parameter Selection

The capacity for CDMA uplinks for 5 proposed systems is calculated using the capacity expressions developed in the previous subsection. The five systems are ARIES, ELLIPSO, GLOBALSTAR, ODYSSEY, and CELSTAR. The parameters for these systems have been taken from the FCC filings subject to the modifications provided during the Negotiated Rulemaking proceedings. The normalized multiple-access-interference (MAI) term (z in Annex 5.1) has been generalized to include the significant enhancement and degradation factors in the capacity determination. These factors are summarized below:

$$MAI = B_U K_U G_U J_U H_U$$

where

B_U = channel activity factor, $B_U < 1$

K_U = beam overlap factor, c.f. Eq. (2.7a), Annex 5.1

G_U = average fade margin, c.f. Eq. (3.13), Annex 5.1

J_U = power control loss factor

H_U = orbit and beam effects factor

The CDMA capacity is inversely proportional to the MAI factor. Thus each of the above factors impacts the capacity in a dB-for-dB manner.

The values used in the link analysis were provided by the CDMA applicants with the following exceptions:

a)   All channel activity factors were set at 0.5. This value represents the necessity to have a keep-alive low data rate during speech pauses and the generally noisier background of cellular communications. The standard selected for analysis in the European GSM system is 0.6.

b)   The average fade margin values given by the applicants ranged from 1 to 2 dB. The average fade margin expression derived in section 3.3.1 of Annex 5.1 was used in the calculation of a single value. Table 5.4-1 gives the calculated values for certain model parameter conditions. All the applicants are assumed to use dual diversity, and for a shadowing fraction of 0.15 the average fade margin is 1.4 dB.

c)   A diversity combining loss factor, Q_U, has been added to the

required modem signal-to-noise ratio because on the uplink there is no pilot signal to aid in demoduation and combining will suffer some loss relative to ideal. A value of 1 dB has been asigned to this loss factor. Simulation results show a loss of about 0.8 dB for square law combining when the paths are symmetrical. The loss increases for non-symmetrical paths and is about 1.5 dB when there is a 3 dB difference in path signal strength.

d) E_b/N_o values provided by the applicants which were below 4.5 dB were adjusted up to 4.5 dB. This value is supported by extensive simulation tests.

TABLE 5.4-1

FRACTION	ATTEN DB	ATTEN RATIO	DEGRAD DB	DEGRAD RATIO	AVERAGE FADE MARGIN DB	
	NO	DIVERSITY				
0.30	9.00	7.94	7.00	5.01	5.80	
0.25	9.00	7.94	7.00	5.01	5.25	
0.20	9.00	7.94	7.00	5.01	4.60	
0.15	9.00	7.94	7.00	5.01	3.85	
0.10	9.00	7.94	7.00	5.01	3.00	
	DUAL DIVERSITY					
0.30	5.00	3.16	3.00	2.00	1.69	
0.25	5.00	3.16	3.00	2.00	1.60	
0.20	5.00	3.16	3.00	2.00	1.51	
0.15	5.00	3.16	3.00	2.00	1.40	SELECTED
0.10	5.00	3.16	3.00	2.00	1.28	

NOTE: SELECTED VALUE BY CDMA APPLICANTS VARIES FROM 1.0 TO 1.7 DB

The dependence of the capacity on dynamic range requires a link analysis of each system to determine its nominal transmit power for a given source interference density allocation. This analysis used allocations of Power Flux Density (PFD) equal to -140, -143 and -146 dBW/4KHz/m^2. A value of approximately -140 dBW/4KHz/m^2 corresponds to thermal noise at midband and with a 500 K noise temperature. This noise temperature is increased above the nominal 290 K level because of earth-radiated man-made noise. The value of 500 K was used by the CDMA applicants for their calculations. The selected PFD values then correspond to single system interference at 0 dB, 3 dB and 6 dB below the noise floor. In order to determine the maximum average output power, the safety level formula from the IEEE standard[1] was used. This formula gives a minimum value at 1626 MHz of 387 milliwatts. Since this value is a long-term average, voice activity must be included in the calculation of this limit. Vehicular communications would allow a much larger dynamic range.

Finally to complete the dynamic range specification it is nessecary to specify the amount of "headroom" to be reserved below the limit in order to serve shadowed users. The values specified in Table 5.4-1 for the attenuation and compensation factor for the adaptive power control system were assumed. The maximum average fade margin represents the largest average factor increase over nominal conditions which the adaptive power control system can produce. In fading situations where the power control system cannot track the fades instantaneously, the control system must compensate for both the shadowing attenuation and the average degradation due to the fading. Thus the maximum average fade margin is the sum of the attenuation and degradation components in Table 5.4-1 or 8 dB. This value illustrates the importance of diversity in reducing the maximum fade margin. For the Iridium system which does not use diversity,[2] the maximum fade margin has been evaluated as 16 dB.

The unshadowed nominal value for the transmit power is calculated in the link analysis using the peak antenna gain and the factor for orbit and beam effects. Since shadowing is most likely at the beam edges, a minimum antenna gain is calculated as follows. The value

$$h_u = 10^{0.1 \cdot H_u}$$

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[1]   IEEE C95.1-1991, IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields 3 KHz-300 GHz, Clause 4.2.2.1, April 27, 1992.

[2]   Satellite path diversity with world-wide coverage would require about twice as many satellites as the current 66 in the Iridium system.

is the orbit and beam effects factor as a ratio. This factor represents the extra uplink terminal power required because the antenna gain is not perfectly range compensated. If g_{max} and g_{min} are the maximum and minimum beam antenna gain ratios, respectively, the value of h_u is approximately

$$h_u = (0.5g_{max} + 0.5g_{min})/g_{min}$$

Solving for the gain ratio, one has

$$g_{max}/g_{min} = 2h_u - 1$$

The above equation is used to determine the value of minimum beam gain for the nominal unshadowed condition.

The average fade margin is a smaller quantity than the maximum, c.f. Table 5.4-1, last column, because it considers the fraction of time that additional power is required. The choice of average fade margin impacts the capacity as a degrader because it causes an increase in multiple-access-interference. The choice of maximum average fade margin impacts the capacity under the condition when there is insufficient dynamic range to compensate for the additional power required under an interference sharing rule.

The calculation of capacity under a fixed set of shadowing conditions is equivalent to requiring a threshold for outage probability or dropped calls. The fraction of shadowed users varies inversely with fade depth. Hence a lower value of maximum average fade margin implies a larger dropped call rate. Meaningful capacity comparisons require at least similar service performance objectives. Since the choice of these objectives is a business decision, a fade model has been selected which gives an average fade margin which is comparable to the values estimated by the CDMA proponents.

The parameters for the 5 CDMA systems for the analysis herein are specified in Table 5.4-2(a). The values estimated by the CDMA proponents are also included in Table 5.4-2(b) to show the relatively small differences in parameter values.

TABLE 5.4-2(a)

ANALYSIS PARAMETERS

UPLINK:

SYS PARAM		CONST.	ELLIPSAT	GLOBAL	ODYSSEY	CELSAT
BIT RATE	KBPS	4.80	4.80	4.80	4.80	5.00
VOICE		0.50	0.50	0.50	0.50	0.50
BANDW.	MHZ	8.25	8.25	7.50	8.25	8.25
DIV LOSS	DB	1.00	1.00	1.00	1.00	1.00
E/(N+I)	DB	4.80	4.50	4.80	4.50	4.80
BEAMS		10.00	10.00	20.00	16.00	149.00
CLUSTER		1.00	1.00	1.00	1.00	1.00
AVG MARG.	DB	1.40	1.40	1.40	1.40	1.40
ORBIT/ANT	DB	2.90	2.00	1.29	1.50	1.70
POW CONT.	DB	1.50	1.00	1.00	1.00	2.00
BOF	DB	1.00	1.00	1.23	1.25	3.80
DY.RANGE	DB	0.00	6.70	9.20	6.10	11.40
MAX MARG.	DB	8.00	8.00	8.00	8.00	8.00
IDEAL CAP		9042	9688	16439	15501	129330
ASYM CAP		1889	2794	5295	4735	16661

TABLE 5.4-2(b)

PARAMETERS FROM
CDMA APPLICANTS

UPLINK:

SYS PARAM		CONST.	ELLIPSAT	GLOBAL	ODYSSEY	CELSAT
BIT RATE	KBPS	4.80	4.80	4.80	4.80	5.00
VOICE		0.50	0.40	0.50	0.40	0.35
BANDW.	MHZ	8.25	8.25	7.50	8.25	8.25
DIV LOSS	DB	0.00	0.00	0.00	0.00	0.00
E/(N+I)	DB	4.00	4.50	4.80	4.50	4.00
BEAMS		10.00	10.00	20.00	16.00	149.00
CLUSTER		1.00	1.00	1.00	1.00	1.00
AVG MARG.	DB	1.70	1.50	1.00	1.30	1.00
ORBIT/ANT	DB	2.90	2.00	1.29	1.50	1.70
POW CONT.	DB	1.50	1.00	1.00	1.00	2.00
BOF	DB	1.00	1.00	1.23	1.25	3.80
IDEAL CAP		13685	15246	20696	24393	279642
ASYM CAP		2668	4297	7309	7626	39500

5.4.2.3.2 Discussion of Results

Link analyses are used to establish the dynamic range parameter for use in the capacity equation defined in section 5.4.2.1. The link analyses for the 5 systems are given in Annex 5.2, Tables 2.4-8. The ARIES system has the smallest G_{SAT}/R^2 factor of the five which accounts for their small maximum average fade margin (0 dB at PFD=-140, 1.1 dB at PFD = -143 and 1.9 dB at PFD = -146). Thus there is insufficient dynamic range in the ARIES system to meet the fade model criterion of 8 dB.

At larger PFD values, the CDMA systems achieve greater capacity given that there are no dynamic range limitations. However, at the larger PFD values there is less dynamic range to cope with shadowed users and the increased interference that occurs with additional shared systems. Thus there is generally some preferred operating point for the allocated power flux density. Before evaluating the choice of PFD, we examine briefly the numerical results from the parameter set proposed by the CDMA applicants, Table 5.4-2(b) and the parameter set as modified herein, Table 5.4-2(a). For the latter parameter set, we include results from both the Mallinckrodt/Barnett [IWG1-56] analysis for infinite dynamic range and the modified version of this analysis presented by Monsen [IWG1-64]. The capacity results are given in Table 5.4-3. The capacity numbers in the first two columns differ primarily by the 1 dB diversity combining loss and the use of 0.5 channel activity factor for all systems. This comparison illustrates that there is not a dramatic disparity in the parameter numbers used for the CDMA capacity evaluation. Dramatic results do occur, particularly at the higher PFD values, due to